BARTON

Experiments on Engine Balancing with a Special Model

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EXPERIMENTS ON ENGINE BALANCING WITH A SPECIAL MODEL

BY

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

WALTER EDMUND BARTON

ENTITLED EXPERIMENTS ON ENGINE BALANCING WITH A SPECIAL MODEL

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Science in Mechanical Engineering

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Experiments on Engine Balancing with a Special Model.

Since the introduction of high speed engines, the subject of counter-balancing has received much attention. Although counterbalancing adds nothing to its effectiveness as an engine, it reduces vibration which causes large and rapidly varying stresses in the frame and foundation of the engine. By the aid of mathematics the stresses due to the unbalanced forces can be calculated and by the use of a properly designed apparatus, the disturbances due to the vibration of unbalanced parts can be observed.

The model described later was made for studying these disturbing forces. It is a model of a five-cylinder marine engine and was designed by Mr. H. H. Barter as thesis for the degree B.S. in 1904.

Plate 1 shows the assembly of Mr. Barter's design. It consists of a wooden base carrying a pair of disks on an axle which has five cranks, two outside and three inside the disks. The cranks are mutually adjustable, four of the flanges of the crank shaft being divided into degrees for this purpose. To the cranks are connected pistons to which may be attached adjustable weights. Of the twelve variables concerned in the balancing of a five crank engine, eight are susceptible of variation in this apparatus.

If the model be suspended in a vertical position and run unbalanced, it will exhibit the way a marine engine tries to wobble when running under similar conditions. Mounted on rollers it moves backwards and forwards when running unbalanced, but when balanced it

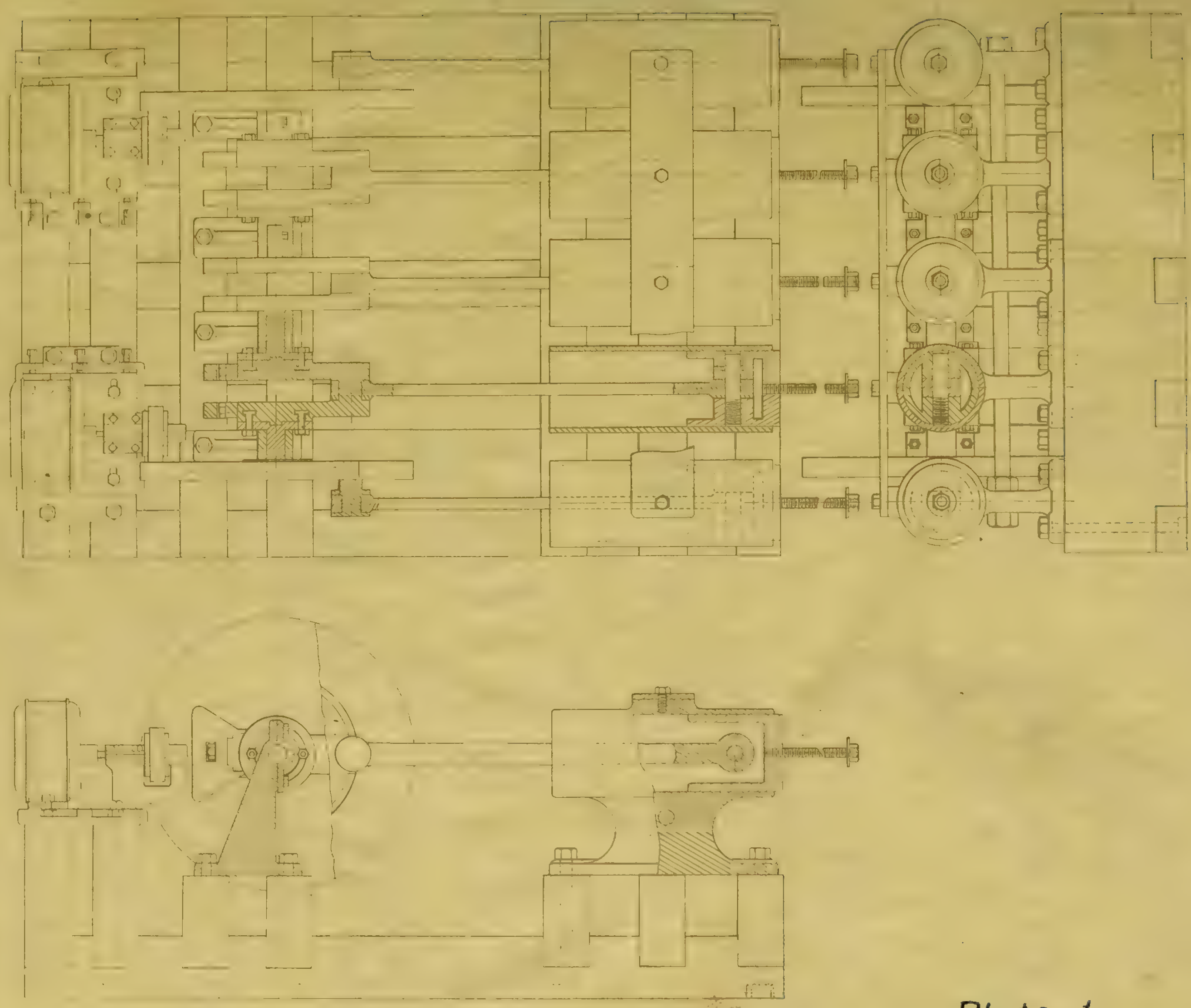

Plate 1.

remains quite still. If it be suspended horizontally by two chains and another spring or an elastic link and run unbalanced, the swaying couple can be seen and the vertical oscillations will indicate the hammer blow.

In 1905 Mr. A. Perry, after making a few minor changes in the details, constructed the machine as designed by Mr. Barter. But when completed the machine proved to be of no value so far as using it for experimental purposes was concerned. Poor design on the one hand and poor workmanship on the other were the causes of the worthless machine.

It was at this stage that the writer took up the work and undertook to make the machine a useful piece of apparatus. Several changes were made in the original design, the principal ones of which are;

(1) a rigid cast iron base, shown

on Plate 2, was substituted for the wooden frame held together with several bolts. This change was made because the wooden base was so affected by atmospheric changes that the main bearings could not be kept properly lined. Even if atmospheric changes had had no effect upon it, it is doubtful if the wooden base could be held rigidly together because of so many joints and bolts to be kept tight.

(2). The motive power was changed by replacing the two $\frac{1}{10}$-horse-power motors with one 2-horsepower motor, and using a chain drive in place of the friction drive. Because of the weight of the moving parts and an unavoidable amount of friction, it was thought best to increase the driving power and make the drive a positive one.

(3). Besides the above changes, it

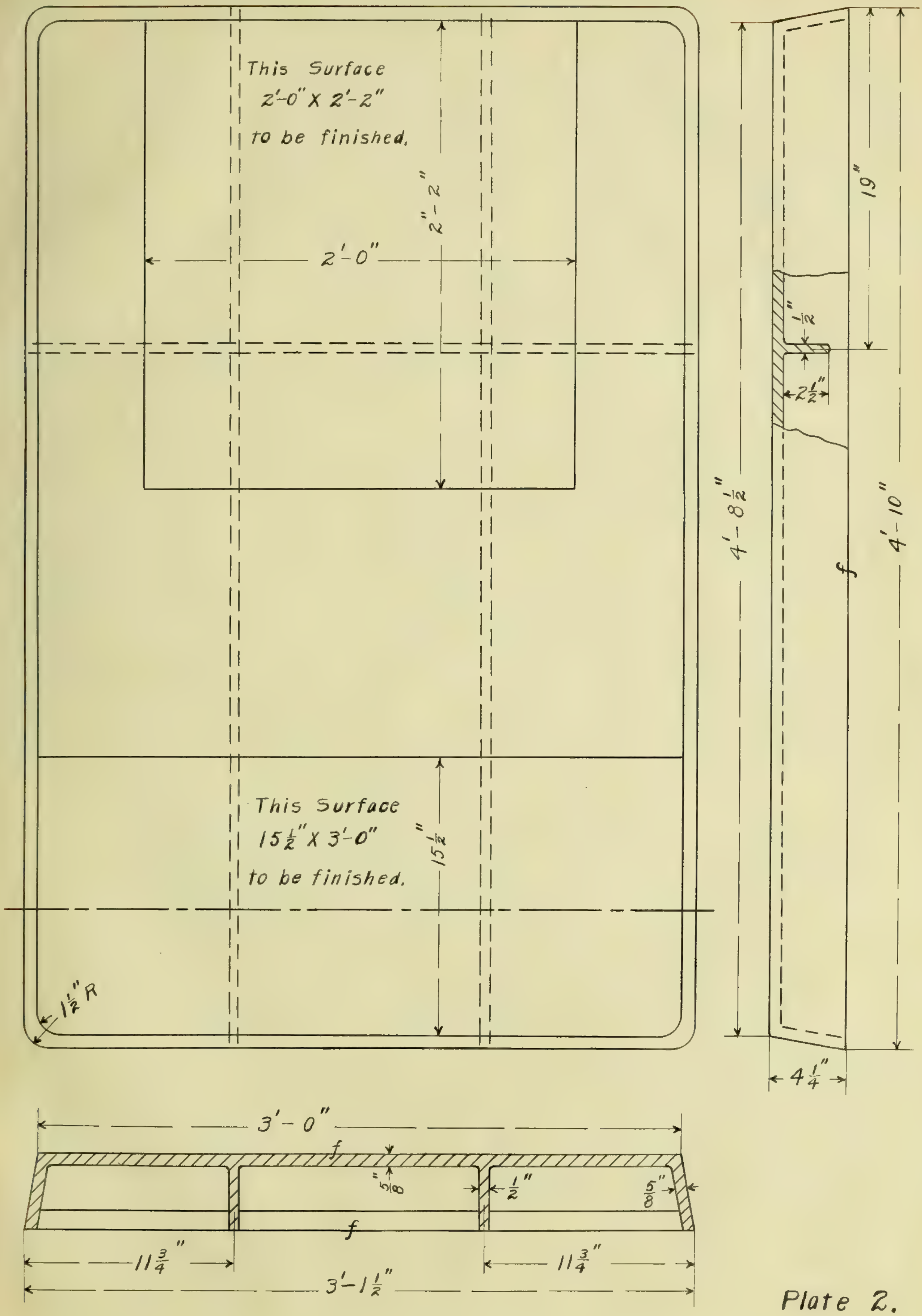
This Surface
2'-0" X 2'-2"
to be finished.
2'-2"
2'-0"
This Surface
15½" X 3'-0"
to be finished.
15½"
1½" R
19"
½"
2½"
4'-8½"
4'-10"
f
4¼"
3'-0"
f
5/8"
½"
5/8"
f
11¾"
11¾"
3'-1½"

Plate 2.

was found necessary to make new main bearings in order to secure a good alignment; and the flanges of the crank-shaft had to be re-faced in order to make the shaft run true when put together. A feature not mentioned in the original design but which was thought to be of convenience was the dividing of the flanges of the crank-shaft into degrees. To prevent any slipping between the base and parts attached to it, dowel-pins were put through the parts into the base.

A photograph of the completed machine is shown in Fig. 1.

Before assemblying the machine for running, the pistons and connecting rods were weighed to nearest half ounce and the position of the center of gravity of the connecting rods located by balancing them on a knife edge. The following table gives the

Fig. 1.

weights, lengths etc., relating to the machine as explained in the notation. The number of the pistons, cranks, etc., in the table refers to the corresponding numbers stamped on the cylinders of the machine.

G = Weight of piston in pounds
R = " " connecting rod in pounds
l = Length " " " " inches
d = Distance in inches from center of gravity of connecting rod to center of wrist pin
a = Distance in inches from center line of cylinder No. 1 to center line of any other cylinder
s = That part of the weight of the connecting rod which acts as a reciprocating weight $= \frac{l}{d} R$

No	G	R	l	d	s	a
1	17.19	10.94	24.97	12.87	5.64	0
2	17.44	10.59	24.97	12.97	5.50	7.5
3	17.55	10.47	24.97	13.00	5.45	14.41
4	16.94	10.44	24.97	12.81	5.35	21.41
5	17.34	10.31	24.94	12.87	5.32	28.95

When the machine was completed it was suspended in a horizontal position and tested by the application of the conditions stated in the following two problems. The solution, only, of these problems is given here; the method of solution may be found in Professor W. E. Dalby's "Balancing of Engines," pp. 64-66 and 158-161.

Problem 1:- Given $M_4 = 30$ pounds $M_5 = 33$ pounds, and $\theta_2 = 270°$; $\theta_3 = 195°$; $\theta_4 = 135°$ and $\theta_5 = 0°$, where M_4 and M_5 = total weight of reciprocating parts corresponding to cylinders 4 and 5, and θ_2, θ_3 etc. denote the angles measured in an anticlockwise direction, which the cranks 2, 3 etc., make with the horizontal, as shown in Fig. 2. Find the values of M_1, M_2, M_3 and θ_1 that the reciprocating masses may be in balance among themselves.

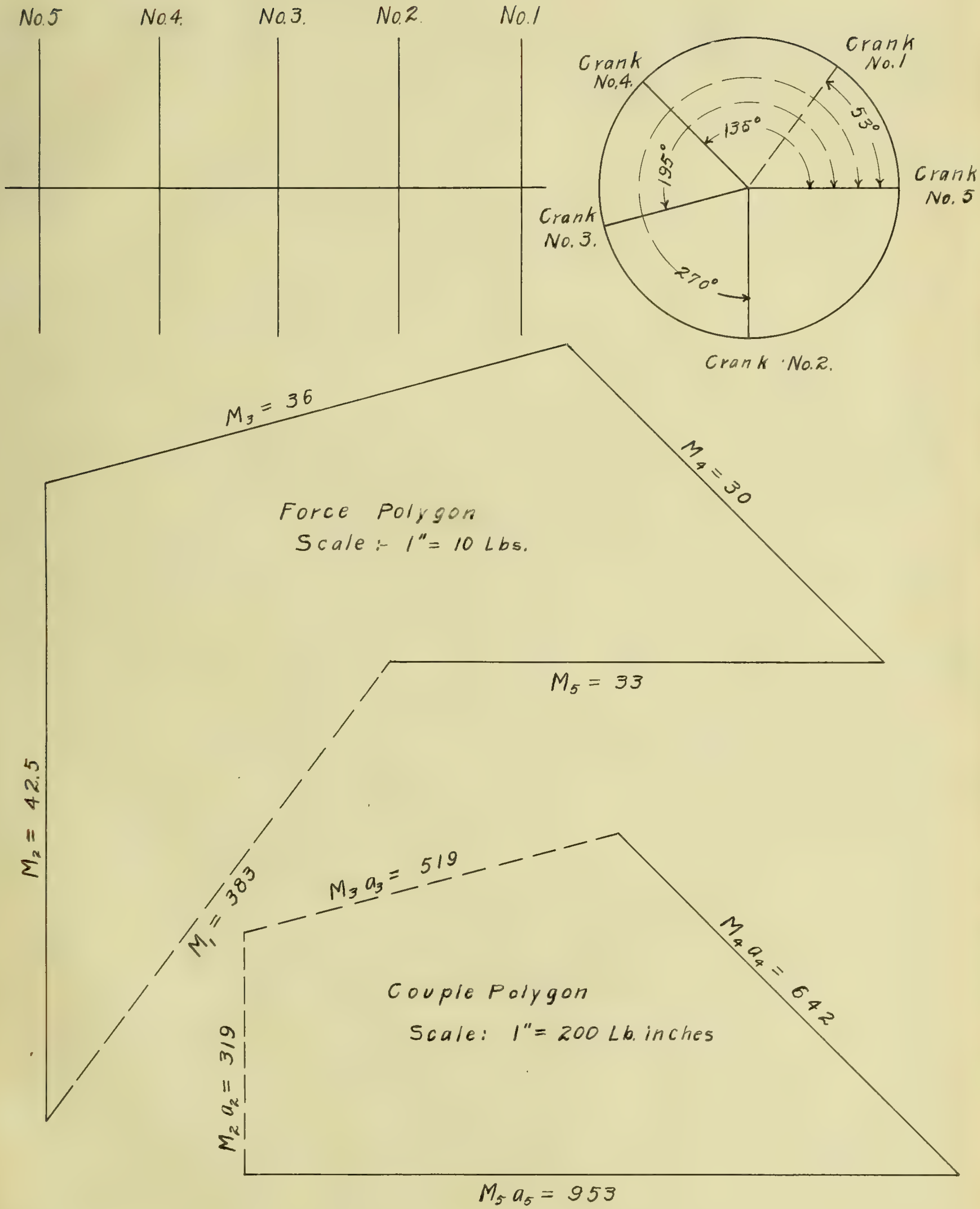
No.5
No.4.
No.3.
No.2.
No.1
Crank No.1
Crank No.4.
135°
53°
195°
Crank No. 5
Crank No. 3.
270°
Crank No.2.
M₃ = 36
M₄ = 30
Force Polygon
Scale :- 1" = 10 Lbs.
M₅ = 33
M₂ = 42.5
M₁ = 383
M₃ a₃ = 519
M₄ a₄ = 642
Couple Polygon
Scale: 1" = 200 Lb. inches
M₂ a₂ = 319
M₅ a₅ = 953

FIG. 2.

Solution:- Taking the reference plane at crank No. 1, we obtain the following couples;

$M_5 a_5 = 33 \times 28.95 = 955$ pound inches.

$M_4 a_4 = 30 \times 21.41 = 642.5$ " "

By constructing the couple polygon and mass polygon as shown in Fig. 2. the unknown quantities can be found. Thus from the couple polygon,

$M_3 a_3 = 519$ pound inches; whence $M_3 = \frac{519}{14.41} = 36$ lbs.

$M_2 a_2 = 319$ " " ; whence $M_2 = \frac{319}{7.5} = 42.5$ lbs.

Adding these quantities to the force polygon and closing it with the side M_1 we find that

$M_1 = 38.3$ pounds and

$\theta_1 = 53°$

Problem 2:- Given $M_3 = 50$ pounds, and $\theta_1 = \theta_5 = 0°$, $\theta_2 = \theta_4 = 120°$ and $\theta_3 = 240°$; Find values of M_1, M_2, M_4 and M_5 so that

the reciprocating masses will be in balance amongst themselves.

Solution:- Since the angles are all given it will be necessary to construct only the force diagram, which is shown in Fig 3. Taking the reference plane at crank No. 3, and taking M_3 as unity the other masses will be proportional to the numbers placed below them in the following rows:-

$$M_1 : M_2 : M_3 : M_4 : M_5$$

$$\frac{14.41}{28.95} : \frac{6.91}{13.91} : 1 : \frac{7}{13.91} : \frac{14.54}{28.95}$$

From the diagram Fig. 3 it is seen that $M_1 + M_5 = 50$ pounds and $M_2 + M_4 = 50$ pounds. Making use of the proportion stated above we find that.

$M_1 = \frac{14.41}{28.95} \times 50 = 24.87$ pounds

$M_2 = \frac{6.91}{13.91} \times 50 = 24.81$ "

$M_4 = \frac{7}{13.91} \times 50 = 25.19$ "

$M_5 = \frac{14.54}{28.95} \times 50 = 25.13$ "

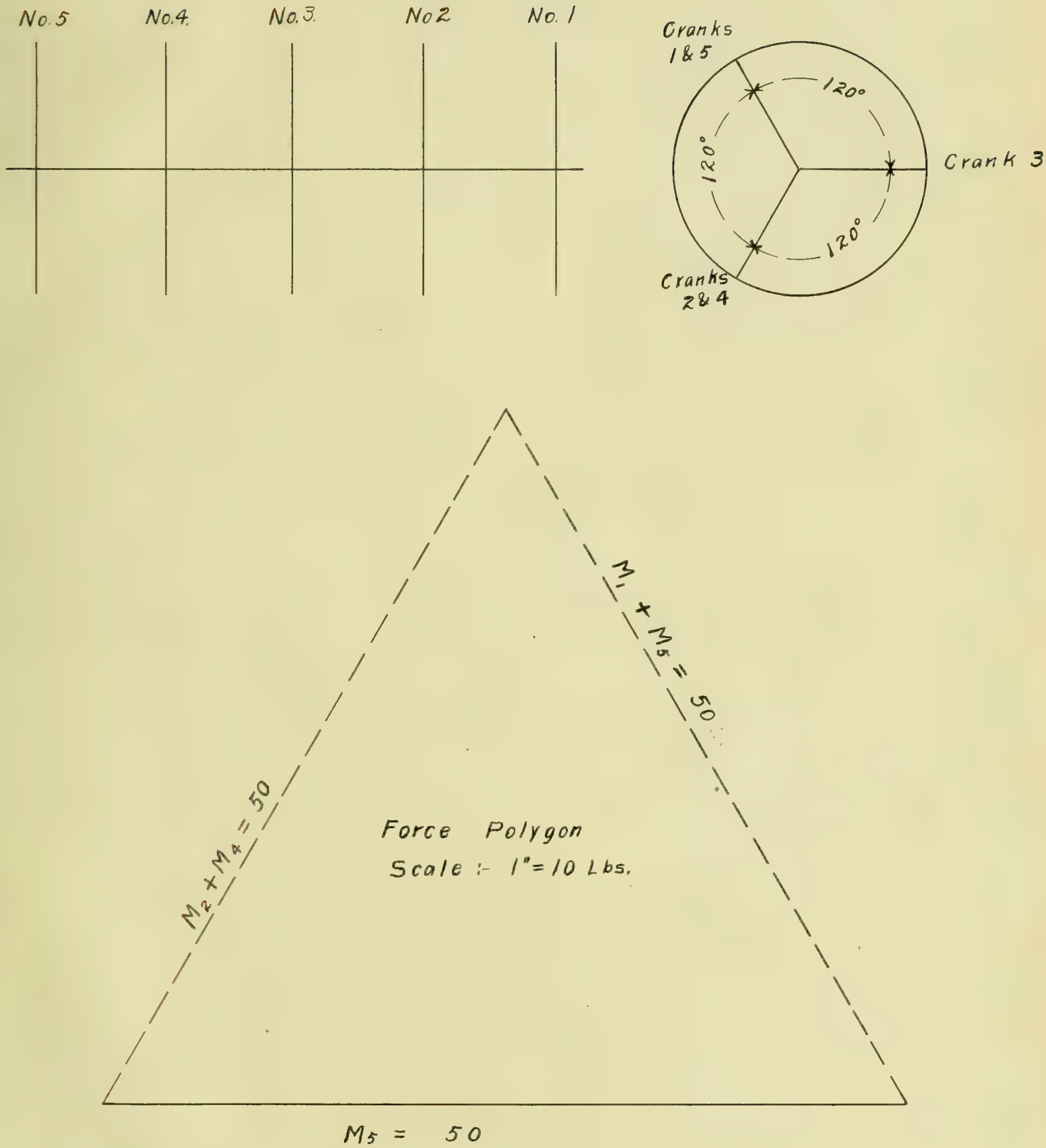
No. 5
No. 4.
No. 3.
No 2
No. 1
Cranks 1 & 5
120°
120°
Crank 3
120°
Cranks 2 & 4
$M_1 + M_5 = 50$
$M_2 + M_4 = 50$
Force Polygon
Scale :- 1" = 10 Lbs.
$M_5 = 50$

Fig. 3.

When the machine was run under the conditions stated in the abov problems it remained quite still, thus showing that it serves well the purpose for which it was made, namely, the study of the various problems of engine balancing.

Other problems which would form interesting experiments with this apparatus are;

(a) Disconnect the center piston and set cranks 1 and 2, 180° apart and cranks 4 and 5, 180° apart but 90° with cranks 1 and 2. This would illustrate the balanced compound locomotive.

(b) Disconnect pistons 2, 3 and 4, and set cranks 1 and 5 90° apart. This would illustrate the simple locomotive.